EXAMINATION OF THE COSTS, BENEFITS AND ENERGY CONSERVATION ASPECTS OF THE NASA AIRCRAFT FUEL CONSERVATION TECHNOLOGY PROGRAM

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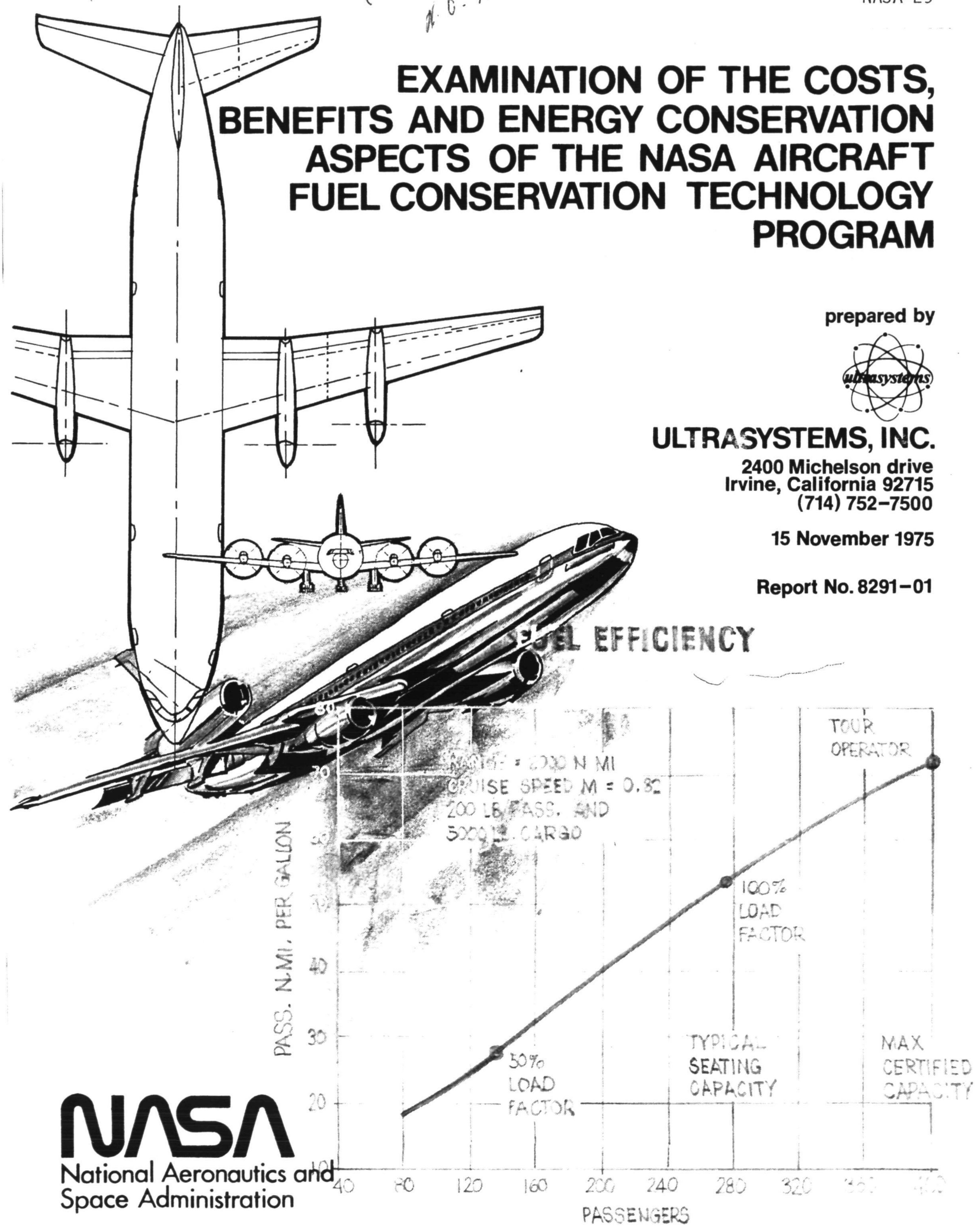
15 November 1975

Report No. 8291–01



National Aeronautics and Space Administration

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PREPARED FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C.
(UNDER CONTRACT NO. NASW-2859)

15 NOVEMBER 1975

ABSTRACT

This report is concerned with an investigation into the costs and benefits of the NASA Aircraft Fuel Conservation Technology Program. Consideration is given to a present worth analysis of the planned program expenditures, an examination of the fuel savings to be obtained by the year 2005 and the worth of this fuel savings relative to the investment required, a comparison of the program funding with that planned by other Federal agencies for energy conservation, an examination of the private industry aeronautical research and technology financial posture for the period FY 76 - FY 85, and an assessment of the potential impacts on air and noise pollution.

To aid in the analysis of this NASA program, a computerized fleet mix forecasting model was developed. This model enables the estimation of fuel consumption and present worth of fuel expenditures for selected commercial aircraft fleet mix scenarios. A detailed description of this model is presented in Appendix A of this report.

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1.0 INTRODUCTION

1.1 Overview of NASA Program

The NASA Aircraft Fuel Technology Program consists of six major programs which could result in conservation of fuel use in air transport. Three of these are evolutionary improvements in propulsion and aerodynamics, whereas the other three (turboprops, laminar flow control and composite primary aircraft structures) represent attempts to develop technology that is considerably different from that in current use in civil air transports.

The specific technology programs within the overall program can be summarized as follows:

(1) Engine Component Improvement

- Develop improved performance components for new production of current engines.
- Conduct diagnostic testing of in-service engines to identify sources of performance degradation.
- Estimated average fuel savings of 5% over current engines.

(2) Fuel Conservative Engine

- Explore the potential of advanced technology turbofans and unconventional propulsion concepts to reduce energy requirements for future aircraft.
- Estimated average fuel savings of 10-15% relative to the technology now available.

(3) Turboprop

- Demonstrate acceptable performance and passenger comfort of a turboprop transport for Mach 0.8 at 30,000 ft. altitude.
- Estimated average fuel savings of 15-20% over turbofan engines employing the same level of technology in the core.

(4) Fuel Conservative Transport

- Demonstrate the fuel conservation potential of advanced aerodynamic technology, improved propulsion system integration, and the incorporation of active controls in aircraft design.
- Estimated average fuel savings of 10-20% as compared to the technology incorporated in the current wide-body transports.

(5) Laminar Flow Control

- Develop and demonstrate a practical, reliable and maintainable boundary-layer suction system for viscous drag reduction.
- Estimated average fuel savings of 20-40% depending on the extent of application and on airplane range.

(6) Composite Primary Aircraft Structures

- Accelerate the introduction of composite primary structural components in new production aircraft.
- Estimated average fuel savings of 10-15% compared to all-metal aircraft.

The key to success in this fuel conservation program lies in the individual program implementation and subsequent acceptability of its results by the aircraft manufacturers. The Engine Component Improvement Program could lead to the incorporation of technology improvements in future production of current engines if economically desirable. The purpose of the Fuel Conservative Engine Program would be to supplement the on-going activities in engine design of NASA, the engine manufacturers and the Department of Defense with new efforts that are especially pertinent to fuel conservation and to accelerate the process of making these technologies ready for application to future engines. The Turboprop Program is structured to advance propeller aerodynamics and structures to attain high-speed, high-loading designs that couple high efficiency with low levels of cabin noise

and vibration. The Fuel Conservative Transport Program is based on the need to develop a broader experimental data base and to improve and validate three-dimensional wing design procedures in order for the airframe manufacturers to employ these concepts most effectively in aircraft designs optimized for fuel efficiency. The Laminar Flow Control Program is based on the results of early experiments with the USAF X-21A airplane and recent developments in other technologies, such as lightweight porous composites and pumping systems, to provide the potential for economically viable systems that are reliable and maintainable. Finally, the Composite Primary Aircraft Structures Program is intended to supplement the on-going research efforts of NASA, DOD and the airframe manufacturers to develop the confidence and technology needed to exploit composite structures, and is structured to minimize the risks associated with the use of composites in new production aircraft by industry.

1.2 Program Costs

The funding requirements for the Aircraft Fuel Conservation Technology Program are summarized in Table 1.1, showing a total of $490 million for the Baseline Program and $670 million for the Total Program over the period Fiscal 76 through Fiscal 85. At a 10% cost of capital these amount to a present worth (in FY 76 dollars) of $315 million and $425 million, respectively.

TABLE 1.1 NASA Aircraft Fuel Conservation Technology Program Funding (in millions)

Fiscal Year	Baseline Program	Total Program
76	$ 10	$ 10
77	41	44
78	67	88
79	101	150
80	109	148
81	85	98
82	46	73
83	18	41
84	10	15
85	3	3
	$490	$670
Present Worth (in FY 76 dollars) at 10% Interest	$315	$425
Equivalent Annual Cost at 10% Interest	$ 51	$ 69

2.0 FUEL SAVINGS ANALYSIS

2.1 Fuel Consumption Forecasts

A fuel consumption model was developed (see Appendix A for details) in order to forecast commercial aircraft fuel consumption as a function of fleet mix for selected time periods. In the development of this model it was assumed that aircraft acquisition is linear (i.e., at a constant rate) starting with the first date and ending with the last date a particular aircraft is acquired, and that aircraft retirement schedule is the mirror image of the acquisition schedule. In addition, the model provides for consideration of a number of other factors such as: base year fleet mix inventory, aircraft service lifetime, aircraft fuel consumption rate, average annual revenue passenger miles flown per aircraft, introduction dates of new and derivative aircraft, annual forecasts of revenue passenger miles, block hours per airborne hour by aircraft type, available seat miles per airborne hour by aircraft type, fuel consumption per block hour by aircraft type, and average number of seats per aircraft.

In order to use this model for evaluation of the Aircraft Fuel Conservation Technology Program, two scenarios of aircraft usage were postulated, namely: (1) Baseline Without NASA Program and (2) Baseline With NASA Program. Before describing the two scenarios used by Ultrasystems for the analysis of potential savings resulting from the NASA research effort the following comments appear appropriate:

a) The entire airline growth and new equipment requirements situations are in an extremely unstable condition. This has been brought on by a number of factors, some of which are (1) the world-wide, unsettled, economic situation (recession accompanied by inflation); (2) the rapid escalation of fuel costs in the last 2-3 years; (3) the apparent

over-buy of new wide-body aircraft which has taken place in the last five years; (4) the lack of any consistent trends in the traffic growth/decline picture; and (5) the potential for deregulation actions by the CAB.

b) As a result of the above, estimates concerning both short- and long-term outlook for the airlines can vary greatly. Many times, estimates reflect experience of the individual estimator, i.e., a particular airline's problems, a manufacturer's desire for sales or a politician's position on regulation. Even when a rational group of people from the various segments of the commercial airline community try to produce an objective assessment of the future, estimates can vary.

c) The scenarios that Ultrasystems proposes for use in this analysis have been created as objectively as possible. All of the recent data made available to NASA by the various manufacturers and airlines, under contract to NASA-Ames, have been examined. Many other pieces of data available from ATA, the CAB and the most recent articles in aviation/trade journals have been examined. The scenarios do not reflect individual airlines or airline manufacture problems or postulates. Rather they reflect an overall assessment of how the industry as a whole will grow/change/etc. over the thirty year period 1975-2005. NASA-Ames has concurred in the reasonableness of the Ultrasystems' scenarios.

d) When the estimates of fuel consumption, shown in this section, are examined, it should be kept in mind that the absolute values can be different if one postulates different scenarios. On the other hand, if one examines the parametric analysis results, shown in Table 2.4, it is clear that the factors which have the most effect on fuel savings remain so, under varying conditions. In addition, when the parameters which have bearing on postulated fuel savings are varied over a range which includes almost

everyone's range of estimates, the variation in savings varies ±4%, except for delay in introduction date (Item (3), Table 2.4). This parameter must, under any analysis, be considered the most critical to achievement of incremental fuel savings due to the proposed NASA Technology Program.

In the first scenario development consideration was given to recent airline action on new aircraft buys, the types of derivative/new aircraft which the aircraft manufacturers are presently discussing (such as 747SR - multiple configurations, DC-X-200, L-1011 modifications - stretch and shorten, etc.), and NASA estimates of new technology incorporation into commercial airlines without the expended NASA research effort. The specific characteristics of the Baseline Without NASA Program scenario can be described as follows:

LONG-RANGE AIRCRAFT

a) It is estimated that a derivative four-engine (747-SR class) aircraft will be introduced by 1980. This aircraft will take advantage of improved engine fuel consumption technology, some composite structures and perhaps the supercritical wing. Overall fuel savings is estimated at 18%.
b) By 1990, essentially a new 3/4 engine aircraft will be introduced. Size-wise it will be equivalent to a stretched B-747. It will use the latest propulsion technology, supercritical wing, extensive use of composite structures and active controls. Overall fuel savings is estimated at 35%.
c) Various improved versions or models of the three engine wide-body aircraft will be introduced into the fleet by 1980. These will utilize available improved propulsion and some composite structures for an estimated overall savings of 10%.

MEDIUM-RANGE AIRCRAFT

a) It is postulated that the present fleet of three-engine narrow-body aircraft will be continued beyond the normal fifteen year service life. This extension is estimated to be seven additional years based on:

- Rework of the aircraft, thus adding approximately 20,000 hours capability to the airframe.
- Average utilization of 3,000 hours/year

Overall fuel savings will be minimal, say, 2-5% per year.

b) Ultrasystems is postulating a 2/3 engine wide-body replacement for this aircraft in 1983. It is believed that the design of aircraft is such today that the distinction between narrow-body/wide-body will have essentially disappeared by this time, i.e., designs will be based essentially on existing wide-body technology. Increased capacity and technology improvements in propulsion and supercritical wing will result in an estimated overall fuel savings of 20%.

c) A derivative of this aircraft will appear by 1995 which will incorporate, in addition to the above, extensive use of composite structures and active controls. Overall fuel savings is estimated at 30%.

SHORT-RANGE AIRCRAFT

a) A derivative two-engine narrow body should be available by 1982. Improved propulsion will provide overall estimated fuel savings of 5%.

b) A new two-engine narrow-body will be introduced in 1990. This aircraft will include supercritical wing, composite structures and active controls plus additional propulsion technology. Overall fuel savings is estimated at 25%.

Table 2.1 provides a summary of this forecast.

TABLE 2.1 Baseline Without NASA Program Forecast of Aircraft Fleet Mix

MOD 1	MOD 2	MOD 3	MOD 4	MOD 5	MOD 6
CLASS 1 TF 4 ENG WB (B-747)	D4EWB INT = 80 PFSV = 18	N3/4EWB INT = 90 PFSV = 35			
CLASS 2 TF 3 ENG WB (DC-10, L-1011)	D3EWB INT = 80 PFSV = 10	D3EWB INT = 85 PFSV = 20	N3/4EWB INT = 90 PFSV = 35		
CLASS 3 TF 4 ENG NB (LONG STAGE) (B-707, DC-8, C-990, B-720)	CURRENT TF 3 ENG WB INT = 75	D3EWB INT = 80 PFSV = 10	D3EWB INT = 85 PFSV = 20	N3/4EWB INT = 90 PFSV = 35	
CLASS 4 TF 4 ENG NB (MEDIUM STAGE) (B-707, DC-8, C-990, B-720)	CURRENT TF3ENB (B-727) 22 YR LIFE	N2/3EWB INT = 83 PFSV = 20	D2/3EWB INT = 95 PFSV = 30		
CLASS 5 TJ 4 ENG NB (B-707, DC-8, C-880)	CURRENT TF3ENB (B-727) 22 YR LIFE	N2/3EWB INT = 83 PFSV = 20	D2/3EWB INT = 95 PFSV = 30		
CLASS 6 TF 3 ENG NB (B-727)	N2/3EWB INT = 83 PFSV = 20	D2/3EWB INT = 95 PFSV = 30			
CLASS 7 TF 2 ENG NB (B-737, DC-9, BAC-111)	D2ENB INT = 82 PFSV = 5	N2ENB INT = 90 PFSV = 25			

LEGEND

- INT = Date of introduction
- D = Derivative
- TF = Turbofan
- E = Engine
- WB = Wide body
- NB = Narrow body
- 3/4 = 3 or 4
- PFSV = Percent fuel savings
- N = New aircraft
- TP = Turboprop

The second scenario represents the incorporation of the anticipated Aircraft Fuel Technology Program results into the first scenario — thus called the Baseline With NASA Program scenario. As a result, the specific characteristics of this scenario can be described as follows:

LONG-RANGE AIRCRAFT

a) As in the baseline case, it is assumed that a derivative four engine (747-SR class) aircraft will be introduced by 1980. The aircraft will take advantage of improved engine fuel consumption technology, some composite structures and perhaps the supercritical wing. Overall fuel savings is estimated at 18%.

b) The new 3/4 engine aircraft proposed for introduction by 1990 in the baseline case, will be available in 1985 with the NASA technology program. It will be equivalent to a stretched B-747, use late propulsion technology, supercritical wing, make extensive use of composite structures and incorporate some active controls. Overall fuel savings is estimated at 30%.

c) As in the baseline case, a stretched derivative of the present three engine wide-body aircraft will be introduced by 1980. Overall fuel savings is estimated at 10%.

d) Various derivatives of the three engine wide-body aircraft will be introduced into the fleet by 1985. These aircraft will be stretched, have improved propulsion and some composite structure technology incorporated. Overall fuel savings is estimated at 28%.

e) By 1992 a new 3/4 engine wide body aircraft making maximum utilization of the output from the NASA technology program will be introduced. This aircraft will incorporate in addition to stretching, improved propulsion, extensive use of composites and active controls, and laminar flow control. Overall fuel savings is estimated at 50%.

MEDIUM RANGE AIRCRAFT

a) Incorporation of the NASA technology program output will allow earlier introduction of a new 2/3 engine wide body replacement aircraft by 1982 rather than 1983 as shown in the baseline program. Overall fuel savings will be improved from the baseline program by 5%, for an overall fuel savings of 25%.

b) A new 2/3 engine wide-body aircraft will be introduced by 1990. This aircraft will incorporate all available propulsion, composite structure, super critical wing and active controls capability. In addition, it will incorporate turboprop or laminar flow control technology. Overall fuel savings is estimated at 50%.

SHORT RANGE AIRCRAFT

a) The derivative short range aircraft available by 1982 (as shown in the baseline program) should be available with an additional 5% fuel savings capability due to NASA technology program inputs. Overall fuel savings is estimated at 10%.

b) A new two-engine turboprop narrow-body transport utilizing latest propulsion technology, composite structure, supercritical wing and active controls will be introduced by 1990. Overall fuel savings is estimated at 50%.

Table 2.2 provides a summary of this forecast.

To evaluate the impact of the NASA Aircraft Fuel Conservation Technology Program on the projected growth in revenue passenger miles, the previously described fleet model was used together with the following assumptions:

(1) there will be an increase of 7% per year in RPM from 1975 until 1985 and thereafter the annual increase will be 5.5% until 2005;

TABLE 2.2 Baseline With NASA Program Forecast of Aircraft Fleet Mix

MOD 1	MOD 2	MOD 3	MOD 4	MOD 5	MOD 6
CLASS 1 TF 4 ENG WB (B-747)	D4EWB INT = 80 PFSV = 18	N3/4EWB INT = 85 PFSV = 30	N3/4EWB INT = 92 PFSV = 50		
CLASS 2 TF 3 ENG WB (DC-10, L-1011)	D3EWB INT = 80 PFSV = 10	D3EWB INT = 85 PFSV = 28	N3/4EWB INT = 92 PFSV = 50		
CLASS 3 TF 4 ENG NB (LONG STAGE) (B-707, DC-8, C-990, B-720)	CURRENT TF 3 ENG WB INT = 75	D3EWB INT = 80 PFSV = 10	D3EWB INT = 85 PFSV = 28	N3/4EWB INT = 92 PFSV = 50	
CLASS 4 TF 4 ENG NB (MEDIUM STAGE) (B-707, DC-8, C-880)	CURRENT TF 3 ENG NB (B-727) 22 YR LIFE	N2EWB INT = 82 PFSV = 25	N2/3EWB INT = 90 PFSV = 50		
CLASS 5 TJ 4 ENG NB (B-707, DC-8, C-880)	CURRENT TF 3 ENG NB (B-727) 22 YR LIFE	N2EWB INT = 82 PFSV = 25	N2/3EWB INT = 90 PFSV = 50		
CLASS 6 TF 3 ENG NB (B-727)	N2/3EWB INT = 82 PFSV = 25	N2/3EWB INT = 90 PFSV = 50			
CLASS 7 TF 2 ENG NB (B-737, DC-9, BAC-111)	D2ENB INT = 82 PFSV = 10	N2ENB (TP) INT = 90 PFSV = 50			

LEGEND

INT = Date of introduction
D = Derivative
TF = Turbofan
E = Engine
WB = Wide body
NB = Narrow body
3/4 = 3 or 4
PFSV = Percent fuel savings
N = New aircraft
TP = Turboprop

(2) aircraft service life is 15 years for all aircraft except the B-727 which is assumed to be 22 years;

(3) load factor is constant at 55%

(4) the distribution of RPM by stage length is 44% for long range and medium range aircraft and is 12% for short range aircraft.

Figure 2.1 provides an illustration of this impact, showing a projected increase from 195 billion RPM in 1975 to 1.106 trillion RPM in 2005 (i.e., 567% or, equivalently, an average of approximately 6% per year). These results were derived using the Baseline With NASA Program scenario forecast of Table 2.2.

Table 2.3 provides a comparison of the projected annual fuel consumption in billions of barrels of oil for the Baseline Without NASA Program and the Baseline With NASA Program for the time period 1975-2005. By 2005 the projected savings to be obtained as the result of implementing the Aircraft Fuel Conservation Technology Program is estimated to be 247.3 million barrels of oil annually or, equivalently, 677,500 barrels per day (BPD). The cumulative savings over the 30-year period is estimated at 2.075 billion barrels of oil, which amounts to an overall savings of nearly 12%. Figure 2.2 provides a graphical illustration of this comparison based on identification of significant aircraft introductions.

2.2 Parametric Analysis of Fuel Savings

In order to examine the sensitivity of the projected fuel savings from implementation of the NASA Aircraft Fuel Conservation Technology Program due to changes in the assumptions employed, the fleet model was used to assess the impact due to the following types of changes:

(1) changing the service life from 15 years to 20 years for all aircraft except the present B-727 fleet

(2) reducing the projected fuel savings by 5% and 10% (i.e., a 50% savings would be reduced to 45% and 40%, respectively, but in no case would it be reduced below zero or the assumed baseline case savings)

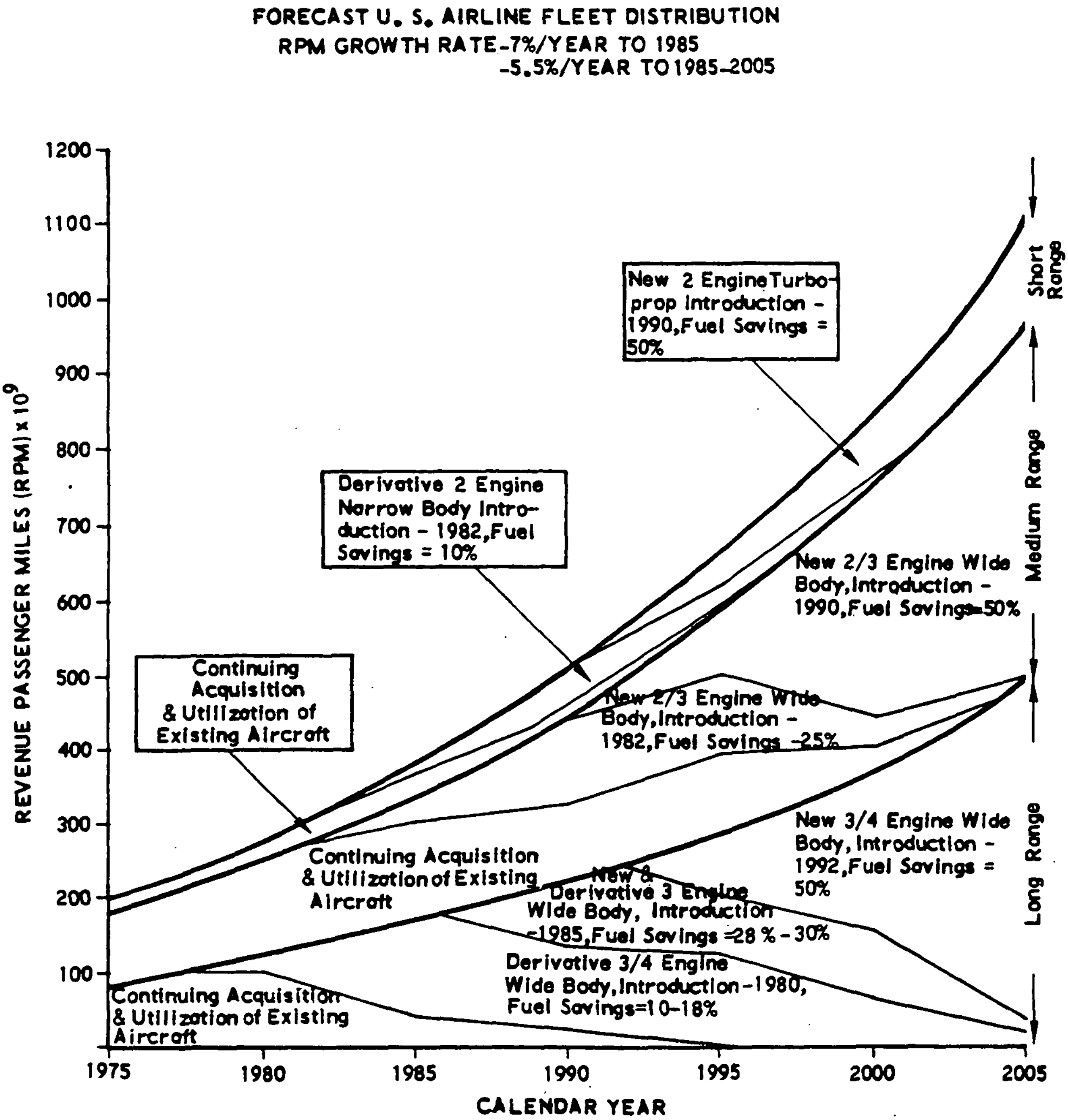

FIGURE 2.1 Revenue Passenger Mile Forecast Based on Implementation of the NASA Aircraft Fuel Conservation Technology Program

TABLE 2.3 Comparison of U.S. Airlines Fuel Consumption Baseline Without NASA Program Versus Baseline With NASA Program

Year	Annual Fuel Consumption (in billion barrels)		Savings (in billion barrels)	Percent Savings
	Baseline	NASA Program		
1975	.2587	.2587	0	0
1976	.2760	.2760	0	0
1977	.2935	.2935	0	0
1978	.3114	.3114	0	0
1979	.3307	.3307	0	0
1980	.3515	.3515	0	0
1981	.3736	.3736	0	0
1982	.3973	.3973	0	0
1983	.4222	.4170	.0052	1.2
1984	.4436	.4384	.0052	1.1
1985	.4609	.4559	.0050	1.0
1986	.4809	.4754	.0055	1.1
1987	.5008	.4938	.0070	1.4
1988	.5202	.5092	.0110	2.1
1989	.5410	.5259	.0151	2.8
1990	.5632	.5439	.0193	3.4
1991	.5864	.5571	.0293	5.0
1992	.6107	.5711	.0396	6.5
1993	.6361	.5802	.0559	8.8
1994	.6627	.5900	.0727	10.9
1995	.6909	.6006	.0903	13.1
1996	.7116	.6108	.1008	14.2
1997	.7335	.6219	.1116	15.2
1998	.7559	.6294	.1265	16.7
1999	.7790	.6353	.1437	18.5
2000	.8029	.6415	.1614	20.1
2001	.8300	.6523	.1777	21.4
2002	.8576	.6625	.1951	22.8
2003	.8882	.6736	.2146	24.2
2004	.9209	.6857	.2352	25.5
2005	.9556	.7083	.2473	25.9
TOTAL	17.948	15.873	2.075	11.6

NOTE: Inputs used in the computer model to generate these results are presented in Appendix C.

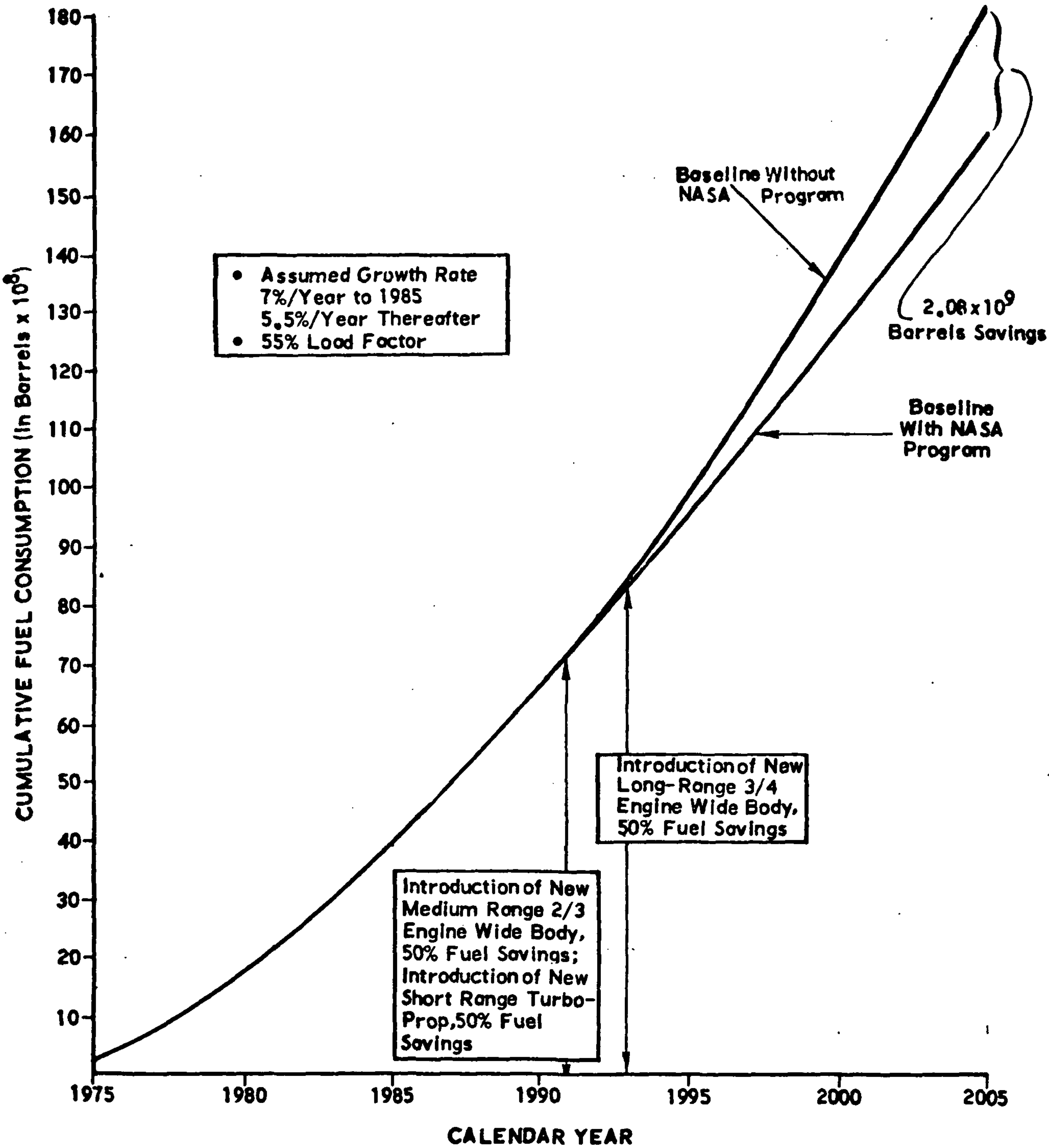

FIGURE 2.2 Comparison of U.S. Airlines Fuel Consumption Baseline Without NASA Program Versus Baseline With NASA Program

(3) delaying the introduction dates of new and derivative aircraft by 2 and 5 years
(4) varying the assumed annual growth rate in revenue passenger miles to 2%, 4% and 8%
(5) varying the assumed constant load factor to 60% and 65%.

In each case the corresponding changes, if necessary, were made in the computations of fuel consumption for the Baseline Without NASA Program scenario fleet mix. Table 2.4 provides a summary of the results obtained. Recalling from Table 2.3 that the overall savings to be obtained using the basic, or unchanged, assumptions is 11.6%, it can be observed that the projected fuel savings is strongly dependent upon two factors, namely: (1) the estimates of fuel savings to be obtained, and (2) the acceptability or willingness, by the airline industry to introduce the new or derivative fuel efficient aircraft when they are available. For example, if each projected fuel savings is high by at most 10%, then the projected fuel savings would only be 4.8% or 854 million barrels of oil over the time period 1975-2005. If the airlines do not adopt the new or derivative fuel efficient aircraft until as much as 5 years after they become available, then the projected fuel savings would only be 1.3% or 233 million barrels of oil over the same time period. Any combination of over estimation in fuel savings and airline industry purchase delays could drastically reduce the potential benefits to be derived from the Aircraft Fuel Conservation Technology Program.

2.3 Program Costs Versus Fuel Savings Costs

Table 2.3 provided a summary of the estimated annual fuel savings which are expected for Baseline With NASA Program scenario relative to the Baseline Without NASA Program scenario, which represents a program of on-going as well as industry fuel efficiency improvements.

It is of interest to compare the present worth of these savings in terms of the cost for purchased fuel with the program research cost. Two scenarios for fuel prices are assumed. Scenario No. 1 assumes that 1980 domestic fuel prices will reach the level of present international

TABLE 2.4 Parametric Analysis of Fuel Savings as Result of NASA Aircraft Fuel Conservation Technology Program

Case	Cumulative Fuel Consumption (in billion barrels)	Savings Relative to Baseline Without NASA Program: Incremental	Percent
(1) Service Life Increase			
Changed to 20 years for all aircraft except B-727	16.256	1.992*	10.9
(2) Reduction in Fuel Savings Projections			
5% Decrease	16.576	1.372	7.6
10% Decrease	17.094	0.854	4.8
(3) Delay in Introduction Dates of Derivative and New Aircraft			
+ 2 Years	16.641	1.307	7.3
+ 5 Years	17.715	0.233	1.3
(4) Variation in RPM Annual Growth Rate			
2% Per Year	8.466	0.750*	8.1
4% Per Year	11.270	1.253*	10.0
8% Per Year	21.200	3.428*	13.9
(5) Variation in Load Factor			
60%	14.550	1.902*	11.6
65%	13.431	1.756*	11.6

* Same changes were made in the Baseline scenario in order to obtain the true relative savings.

fuel prices, which is 35 cents per gallon, and thereafter will increase at the rate of 7% per annum. Scenario No. 2 assumes that 1980 domestic fuel prices will be 35 cents per gallon and remain at this price through 2005. Assuming a 10% interest rate (or cost of capital), Table 2.5 provides an economic evaluation of the worth of these savings relative to the worth of the research investment in the total NASA program. As can be seen, the benefit-to-cost ratio, measured by the ratio of the present worth of the fuel savings to the present worth of the research investment cost, ranges from 7.5 to 26 for the NASA Aircraft Fuel Conservation Technology Program. This means that for every research dollar spent, the return in savings for purchased fuel ranges from $7.50 to $26.

TABLE 2.5 Present Worth (at 10%) in FY76 Dollars of Fuel Savings Versus Investment Costs

	SCENARIO NO. 1		SCENARIO NO. 2	
	Present Worth of Fuel Savings ($\$10^6$)	Ratio of Fuel Savings Worth to Investment Cost	Present Worth of Fuel Savings ($\$10^6$)	Ratio of Fuel Savings Worth to Investment Cost
NASA Program Relative to Baseline	$11,058	26.0	$3,186	7.5

2.4 Impact on Project Independence Scenarios

In FEA's Project Independence a number of strategies representing different national energy policies were evaluated. This evaluation focussed on how much production could be achieved for each of the various sources of energy under different world oil prices using the AUI-Brookhaven Reference Energy System. In each case, account was taken of the lead times associated with increasing production from each of these sources. Separate projections of supply as a function of price were made up through 1985 for oil, natural gas, coal, nuclear, synthetic fuels, shale oil, solar and geothermal energy.

The demand for each energy product as a function of price was developed. In addition to reductions in demand induced by higher prices, the impact of specific conservation measures was also forecast.

Four strategies considered involved a policy of Business-as-Usual and a policy of Accelerated Supply, each with and without conservation. The characteristics and features of these policies can be described as follows:

(a) Business-As-Usual

This policy assumes the continuation of policies in effect prior to 1973 (except for those controlling oil prices), but that domestic energy demand will grow at substantially lower rates than it has in the past. Coal production will increase significantly and nuclear power will grow to nearly one-third of the total electric power generation. Synthetic fuels will not play a major role between now and 1985. Similarly, it is assumed that geothermal, solar and other advanced technologies will not contribute to our energy requirements until after 1985.

(b) Accelerated Supply

This policy assumes changes in policies to encourage domestic petroleum exploration and production, including accelerated offshore leasing, opening up military reservations for exploration and production, increasing Federal support for petroleum research and development, end of price controls on oil, and removal of regulatory delays in nuclear power development.

(c) Conservation

By conservation is meant the reduction in demand for petroleum by such actions as the setting of minimum mileage standards for new automobiles and providing incentives and standards to increase residential insulation and energy-use efficiency. Incentives would include a gasoline tax and tax credits for retrofit of homes and commercial buildings. Standards include thermal standards for new homes and offices, commercial lighting standards, and appliance efficiency standards.

In summary, the basic policy scenarios considered are:

(1) Business-As-Usual Without Conservation
(2) Business-As-Usual With Conservation
(3) Accelerated Supply Without Conservation
(4) Accelerated Supply With Conservation

Figure 2.3 presents a forecast of annual petroleum consumption demand for the transportation sector based on these four policy scenarios. The Project Independence forecast data covered the period up to 1985 and so beyond 1985 the consumption forecasts are extrapolations, as shown by the dashed segments.

In order to examine the benefits to be derived from the NASA program relative to the Baseline it is of interest to investigate aircraft fuel consumption relative to the consumption demand forecasts of Figure 2.3. For example, Table 2.6 shows that in the case of the Baseline program the percentage of consumption in the transportation sector could range from a low of 12% in 1985 to a high of 24% in 2005 depending on the scenario used, whereas the NASA program would imply a range with a low of 12% in 1985 to a high of 18% in 2005. At the present time, the aviation subsector uses on the order of 13% of the total transportation sector energy. Implementation of the NASA program would thus imply a usage more compatible with the present level of use.

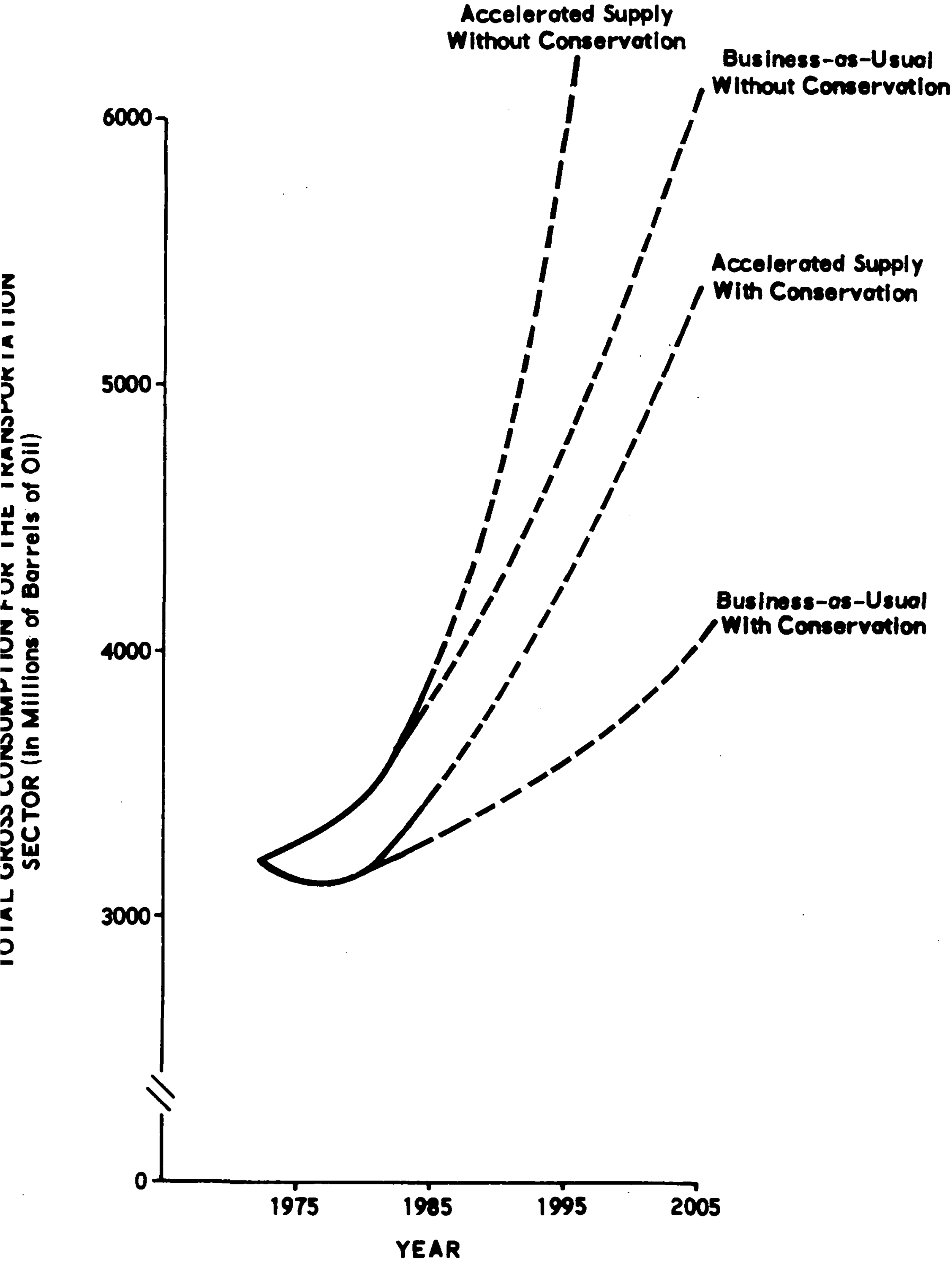

FIGURE 2.3 PROJECT INDEPENDENCE SCENARIOS OF PETROLEUM CONSUMPTION (BASED ON $11 OIL)

TABLE 2.6 Aircraft Fuel Consumption Usage of the Baseline and Total Program Relative to the Project Independence Scenarios

Scenario	Year	Forecast[1]	Aircraft Fuel Consumption Percentage: Baseline	Total Program	Difference in Percentage
Business-As-Usual Without Conservation	1985	3.84	12.0	11.9	0.1
	1990	4.26	13.2	12.8	0.4
	1995	4.78	14.5	12.6	1.9
	2000	5.39	14.9	11.9	3.0
	2005	6.10	15.7	11.6	4.1
Business-As-Usual With Conservation	1985	3.29	14.0	13.9	0.1
	1990	3.42	16.5	15.9	0.6
	1995	3.56	19.4	16.9	2.5
	2000	3.76	21.4	17.1	4.3
	2005	4.02	23.8	17.6	6.2
Accelerated Supply Without Conservation	1985	3.93	11.7	11.6	0.1
	1990	4.68	12.0	11.6	0.4
	1995	5.94	11.6	10.1	1.5
	2000	(2)	--	--	--
	2005	(2)	--	--	--
Accelerated Supply With Conservation	1985	3.46	13.3	13.2	0.1
	1990	3.79	14.9	14.4	0.5
	1995	4.24	16.3	14.2	2.1
	2000	4.77	16.8	13.4	3.4
	2005	5.36	17.8	13.2	4.6

(1) In billions of barrels
(2) Unable to meaningfully estimate.

3.0 FEDERAL ENERGY R, D & D PROGRAMS AND ACTIVITIES

3.1 Relationship to ERDA Technology Goals

The National Plan for Energy Research, Development and Demonstration recently prepared by ERDA contains six basic technology goals. Their respective characteristics are presented in Table 3.1. The Aircraft Fuel Conservation Technology Program would be classified under Goal VI: Increase End-Use Efficiency — in particular, under Transportation Efficiency. In this technology area, the expected impact would be 4.50 million BPD savings in the year 2000. Referring to Table 2.3, the Aircraft Fuel Conservation Technology Program would contribute .442/4.50=.098 or nearly 10% to this savings. Since civil aircraft use on the order of 8-10% of the total energy consumed in the transportation sector, this savings is in proportion to energy usage. The near term, or pre 1985, impact of the NASA program would be negligible.

3.2 Comparison with Other Agency R, D & D Efforts

Table 3.2 provides an illustrative comparison of the Aircraft Fuel Conservation Technology Program budget for FY 76 with the estimated energy R, D & D budgets for six other Federal agencies. The DOT and NASA budgets are the lowest; however, none of the estimated DOT $9.45 million is allocated to the FEA.

Table 3.3 presents FY 76 budget estimates for seventeen Federal agencies, other than ERDA, across twenty one selected R&D areas. Using the ERDA estimate from Table 2.2, an estimate of the total Federal FY 76 energy R&D budget is given by $2.400 +$0.803= $3.203 billion. Approximately 2.4% of these funds are allocated in the transportation energy conservation area. Implementing the Aircraft Fuel Conservation Technology Program in FY 76 would add another $10 million, thus increasing this percentage to (88.2/3213) x 100 = 2.7%. By comparison, the transportation sector consumes 25% of the total energy, which is an order of magnitude larger than the corresponding percentage allocation of energy R&D funds.

TABLE 3.1 Characteristics of ERDA Selected Energy Technology Goals

TECHNOLOGY GOAL	TERM OF IMPACT*	DIRECT SUBSTITUTION FOR OIL & GAS**	R,D&D STATUS	IMPACT IN YEAR 2000*** IN QUADS	IN MILLION BPD
GOAL I: Expanded the Domestic Supply of Economically Recoverable Energy Producing Raw Materials					
Oil and Gas - Enhanced Recovery	Near	Yes	Pilot	13.6	6.80
Oil Shale	Mid	Yes	Study/Pilot	7.3	3.65
Geothermal	Mid	No	Lab/Pilot	3.1-5.6	1.55-2.80
GOAL II: Increase the Use of Essentially Inexhaustible Domestic Energy Resources					
Solar Electric	Long	No	Lab	2.1-4.2	1.05-2.10
Breeder Reactors	Long	No	Lab/Pilot	3.1	1.55
Fusion	Long	No	Lab	---	----
GOAL III: Efficiently Transform Fuel Resources into More Desirable Forms					
Coal - Direct Utilization Utility/ Industry	Near	Yes	Pilot/Demo	24.5	12.25
Waste Materials to Energy	Near	Yes	Comm	4.9	2.45
Gaseous & Liquid Fuels from Coal	Mid	Yes	Pilot/Demo	14.0	7.00
Fuels from Biomass	Long	Yes	Lab	1.4	.70
GOAL IV: Increase the Efficiency and Reliability of the Processes Used in the Energy Conversion and Delivery Systems					
Nuclear Converter Reactors	Near	No	Demo/Comm	28.0	14.00
Electric Conversion Efficiency	Mid	No	Lab	2.6	1.30
Energy Storage	Mid	No	Lab	---	---
Electric Power Transmission and Distribution	Long	No	Lab	1.4	.70
GOAL V: Transform Consumption Patterns to Improve Energy Utilization					
Solar Heat & Cooling	Mid	Yes	Pilot	5.9	2.95
Waste Heat Utilization	Mid	Yes	Study/Demo	4.9	2.45
Electric Transport	Long	Yes	Study/Lab	1.3	.65
Hydrogen in Energy Systems	Long	Yes	Study	---	----
GOAL VI: Increase End-Use Efficiency					
Transportation Efficiency	Near	Yes	Study/Lab	9.0	4.50
Industrial Energy Efficiency	Near	Yes	Study/Comm	8.0	4.00
Conservation in Buildings and Consumer Products	Near	Yes	Study/Comm	7.1	3.55

* Near - now through 1985
Mid - 1985 through 2000
Long - Post-2000

** Assumes no change in end-use device.

***Maximum impact of this technology in any scenario measured in terms of additional oil which would have to be marketed if the technology were not implemented.

SOURCE: A National Plan for Energy Research, Development And Demonstration: Creating Energy Choices for the Future, Vol. 1, The Plan, ERDA-48

TABLE 3.2 Estimated FY 76 Energy Research, Development and Demonstration (R, D & D) Budgets (in millions)

AGENCY	ESTIMATED FY 76 BUDGET	MAJOR THRUSTS
Department of Interior	$ 160	Oil and gas recovery, resource assessment and mining and extractive technology
National Science Foundation	$ 155	Basic research
Environmental Protection Agency	$ 140	Alleviation of environmental damage to energy systems, and measurement and monitoring of health effects and pollutants
Nuclear Regulatory Commission	$ 90	Confirmatory nuclear safety R, D & D and studies on safeguards, safety systems and siting guides
Energy Research and Development Administration	$2,400	Implementation of broad technology goals in fossil energy development, solar, geothermal & advanced energy development, conservation research and development, and nuclear energy development
Department of Transportation	$ 9.45	Energy conservation programs
Federal Energy Administration	$ 42.8	Energy conservation and environment, energy resource development, regulatory programs, policy and analysis, and international energy affairs
National Aeronautics and Space Administration	$ 10	Aircraft fuel conservation technology program

SOURCES:

(1) A National Plan For Energy Research, Development and Demonstration: Creating Energy Choices for The Future, Vol. 1 The Plan, ERDA-48

(2) NASA Aircraft Fuel Conservation Technology Program Task Force Report

(3) Research, Development and Demonstration Analysis of Fiscal Year 1976 DOT R&D Program by R&D Management Objectives: Program Levels for Fiscal Years 1974, 1975, 1976, Transportation Research Activity Information Service Report No. DOT TST 75-10, Dept. of Transportation

(4) **Federal Energy Administration**

(5) **Energy Research and Development Administration**

TABLE 3.3 Selected Federal* Energy R&D FY 76 Estimated Budgets (in Millions) by R&D Area

R&D Area	Estimated FY 76 Budget (in Millions)
Oil and Gas from Underground Sources	$ 1.0
Exploration and Resource Mining	43.2
Energy Resource Mining Technology	56.7
Non-Breeder Reactors	71.9
Direct Solar Conversion	7.9
Solar Electric Applications	15.0
Geothermal	6.0
Fusion	0.4
Breeder Reactors	8.3
Derived Fuels	9.1
Heat and Power from Coal	5.0
Advanced Electric Generation Systems	4.6
Conservation in Electric Energy Systems	7.7
Energy Conservation in Industry	31.8
Conservation in Buildings	33.1
Conservation in Transportation	78.2
Cross Sectoral Conservation	12.1
Environmental Control Technology	105.4
Support to Commercial Nuclear Fuel Cycle	2.8
System Studies and Analyses	23.7
Basic Research	279.3
TOTAL	$803.2

SOURCE: A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future, Vol. 1, The Plan, ERDA-48

*Seventeen agencies represented,not including ERDA.

3.3 Comparison with FEA Activities

The primary energy conservation efforts within the FEA are focussed in the activities of the Office of Conservation and Environment. These efforts include four basic sectors (besides system studies), namely, buildings, industrial, transportation and utilities. Table 3.4 provides a performance comparison of these sector activities in terms of the proposed FY 76 sector budgets and the payoffs (i.e., savings in BPD) to be obtained in 1985 as the result of these expenditures. For example, the 1985 savings in BPD per FY 76 research dollar invested ranges from .18 to .65.

TABLE 3.4 FEA Office of Conservation and Environment FY 76 R&D Budget Estimates and 1985 Energy Savings by Sector

Sector	1985 Energy Savings in BPD	FY 76 Estimate (in millions)	Savings Per Dollar
Buildings	1,653,000	$7.21	.23
Industrial	803,000	4.54	.18
Transportation	2,078,000	3.20	.65
Utilities	756,000	2.00	.38

SOURCE: FEA Office of Energy Conservation and Environment Fiscal 1975 Contract Justification, September 1974

As a comparison of the expected "performance" of the NASA Aircraft Fuel Conservation Technology Program with these FEA efforts, Table 3.5 shows that the savings in BPD to be obtained in 1985 per FY 76 research dollar invested ($425 million at 10% interest) is on the order of .00003 and increases to .0016 by 2005. The NASA program clearly is not a short-term program vis-a-vis the FEA efforts in terms of its payoffs, but is designed to yield long-term payoffs in aircraft fuel consumption.

TABLE 3.5 NASA Aircraft Fuel Conservation Technology Program Savings

Year	Savings in BPD	Payoff in Savings per Research Dollar Invested
1985	13,700	.00003
1990	52,900	.00012
1995	247,400	.00058
2000	442,200	.00100
2005	677,500	.00160

4.0 COMPARISON WITH FEDERAL AND INDUSTRIAL AERONAUTICAL R&D FUNDING

Table 4.1 provides a historical summary of Federal aeronautical R&D funding in the defense and non-defense areas of research and technology and development, industrial R&D funding for aeronautics and a comparison of these funding histories with the gross national product. In these histories, Federal defense funds include those for the Army, Navy, Air Force, Advanced Research Projects Agency, the Aircraft Nuclear Propulsion Program of the Atomic Energy Commission, and the R&D funds reimbursed by the Government to industry as allowable overhead charges on procurement contracts. Federal non-defense funds include those for NASA and the FAA. Industry funds include non-reimbursed industry independent research and development (IR&D) and specific development funds, and those funds provided by universities and foundations. IR&D funds include independent research not reimbursed to industry including that IR&D allocated to civilian sales, other technical effort and bid and proposal activities. Specific development funds include only civil type aircraft, whereas development funds for military aircraft are included under Federal defense funds.

Several observations regarding the data of Table 4.1 are as follows:

(1) Industry funds for aeronautical R&D have increased only 42% since 1963 (an approximate annual increase of 3-1/2%), from $284 million in 1963 to $402 million in 1973, while from 1968 to 1973 these industry funds have decreased by 33%. It appears that industry will contribute less in the future than it has in the past to aeronautical technical advances.

(2) Federal funds for aeronautical R&D are distributed on the order of 22-27% for research and technology and 73-78% for development. Recent trends show 23% for research and technology and 77% for development.

(3) Industry R&D funds represent approximately 11% of the total (industry plus Federal) annual aeronautical R&D funds. This percentage has been steadily declining from a high of 23% in 1968.

TABLE 4.1 Comparison of Federal Aeronautical R&D Funding (in Millions) with Industrial Aeronautical R&D Expenditures and Gross National Product (GNP)

Fiscal Year	Federal Aeronautical R&D Funding: Research & Technology: Defense	Research & Technology: Non-Defense	Development: Defense	Development: Non-Defense	Federal R&D: R&T (%)	Federal R&D: Dev. (%)	Federal R&D: Total	Industry R&D	Total Federal and Industry R&D	Percentage of Total: Federal R&D	Percentage of Total: Industry R&D	GNP	Percentage of GNP: Federal and Industry R&D	Percentage of GNP: Federal R&D	Percentage of GNP: Industry R&D
1963	$485	$ 44	$1,506	$100	$529(26)	$1,606(74)	$2,135	$284	$2,419	88.3	11.7	$ 590,503	0.41	0.35	0.05
1964	475	48	1,464	92	523(25)	1,556(75)	2,079	304	2,383	87.2	12.8	632,400	0.38	0.33	0.05
1965	462	57	1,402	96	519(26)	1,498(74)	2,017	353	2,370	85.1	14.9	684,900	0.35	0.29	0.06
1966	510	42	1,503	211	552(24)	1,714(76)	2,266	445	2,711	83.6	16.4	747,600	0.36	0.30	0.06
1967	526	50	1,405	309	576(25)	1,714(75)	2,290	565	2,855	80.2	19.8	793,500	0.36	0.29	0.07
1968	551	58	1,452	197	609(27)	1,649(73)	2,258	673	2,932	77.0	23.0	864,200	0.34	0.26	0.08
1969	516	63	1,335	235	579(27)	1,570(73)	2,149	609	2,758	77.9	22.1	930,300	0.30	0.23	0.07
1970	588	76	1,811	326	664(24)	2,137(76)	2,801	514	3,315	84.5	15.5	976,400	0.34	0.29	0.05
1971	578	80	1,856	463	658(22)	2,319(78)	2,977	477	3,454	86.2	13.8	1,054,900	0.33	0.29	0.04
1972	654	87	2,177	328	741(23)	2,505(77)	3,246	490	3,736	86.9	13.1	1,158,000	0.32	0.28	0.04
1973	630	109	2,163	327	739(23)	2,490(77)	3,229	402	3,631	88.9	11.1	1,294,900	0.28	0.25	0.03

SOURCE: Joint DOD-NASA-DOT "R&D Contributions to Aviation Progress" (RADCAP) Study, August 1972.

(4) Total aeronautical R&D funds account for approximately (on the average) 0.34% of the gross national product. Federal funds represent 0.29% and industry funds 0.05%, on the average. The latter has been declining in recent years to 0.03%.

(5) Over the time period 1968-1973, non-defense research and technology has averaged 2.6% of the total Federal aeronautical R&D funding — actually ranging from a low of 1.9% in 1966 to a high of 3.4% in 1973.

A general rule of thumb is that IR&D funds represent approximately 5-1/2% of net sales and specific development funds represent approximately 1-1/2% of net sales. As a basis of comparison, an attempt was made to estimate how much industry spends for R&D related to commercial aircraft by reviewing 1974 corporate annual reports of the leading airframe and component manufacturers. Table 4.2 provides a summary of the results obtained and shows that an estimated $468 million was spent for commercial aircraft R&D in 1974, which was nearly 5.9% of commercial sales.

TABLE 4.2 Comparison of Commercial Aircraft Related R&D Expenditures (in Millions) with Sales

	Sales	R&D
Lockheed	$ 811 (1)	$ 28
Boeing	2,131 (2)	102
United Aircraft	1,773 (3)	152
McDonnell-Douglas	1,338 (4)	60
General Electric	1,916 (5)	126
	$7,969	$468 (5.9%)

(1) L-1011 TriStar transport only.
(2) Estimated commercial transportation equipment and related services.
(3) Power sales only.
(4) Commercial aircraft sales.
(5) DC-10 only.

In order to compare the planned NASA Aircraft Fuel Conservation Technology Program funding with industry non-reimbursable expenditures and its ability to support such a program itself, suppose that the Gross National Product increases at the annual rate of 3-1/2%, but industry aeronautical R&D remains constant at 0.03% of GNP. Federal R&D expenditures average 23% for research and technology. Private industry would not necessarily be expected to spend their R&D funds according to the same distribution as the Federal Government — in fact, it would most likely spend less for research and technology. For this reason, three possible cases are considered: 10%, 15% and 20% for research and technology. Table 4.3 provides a comparison of the NASA program with these industry research and technology cases on both a present worth and an annual cost basis (at 10% cost of capital).

With a 15% or more commitment of aeronautical R&D funds for research and technology, private industry would be spending $54-108 million per year over the period FY 76 - FY 85 for on-going efforts. In order for private industry to fund the research efforts of the NASA program would require an additional $69 million per year, thus nearly doubling its present annual investment; hence, it is extremely unlikely that private industry could meet the expected capital requirements of the NASA program and, consequently, Federal support is necessary.

TABLE 4.3 Comparison of NASA Aircraft Fuel Conservation Technology Program Funding with Industry Commercial Aircraft R&T Expenditures (in Millions)

Fiscal Year	Industry R&T 10%	Industry R&T 15%	Industry R&T 20%	NASA Program*
76	$ 43.0	$ 64.5	$ 86.0	$ 10
77	44.6	66.9	89.2	44
78	46.2	69.3	92.4	88
79	47.8	71.7	95.6	150
80	49.4	74.1	98.8	148
81	51.2	76.8	102.4	98
82	53.0	79.5	106.0	73
83	54.8	82.2	109.6	41
84	56.8	85.2	113.6	15
85	58.8	88.2	117.6	3
Present Worth @ 10%	$332	$498	$664	$425
Equivalent Annual Cost @ 10%	$ 54	$ 81	$108	$ 69

* Total + On-Going

5.0 ENVIRONMENTAL CONSIDERATIONS

5.1 Introduction

The environmental impact of the NASA fuel conservation program was investigated with respect to the impact on air pollution emissions generated by low fuel consumption aircraft and the noise generation characteristics of the fuel conservative aircraft.

The objective of this analysis is to describe the impact, if any, that a fuel conservation program will have on aircraft air pollution levels and noise generation characteristics. There are three technology areas undergoing investigation for possible conservation of fuel. These are propulsion systems, aerodynamics, structures and materials. Of these, propulsion systems has the most potential for impact on aircraft air pollutant emissions and noise levels. Aerodynamic and structures improvements in aircraft imply an improvement in flight characteristics which inherently imply lower thrust requirements for the engines and hence lower fuel consumption, lower air pollutant emission rates and lower noise levels. Aerodynamic improvements may have an impact on airframe generated noise levels. Aircraft air pollution emissions are treated in Section 5.2 and noise generation is treated in Section 5.3.

5.2 Air Pollution

5.2.1 Aircraft Emission Characteristics

A detailed description of pollutant formation in jet turbine engines is beyond the scope of this analysis; however, a brief discussion of aircraft emission characteristics is included here by way of introduction to concepts that are introduced later in the analysis.

Aircraft emissions can be divided into two categories, namely, those pollutants formed because of incomplete or inefficient combustion and those pollutants formed because of high combustion temperatures. Carbon monoxide (CO) and hydrocarbons (HC) are examples of pollutants formed because of incomplete combustion. Hydrocarbons are emitted as a result

of unburned fuel and partially oxidated hydrocarbon combustion products passing through the combustion zone before complete combustion has taken place. Carbon monoxide is emitted when combustion generated CO has not had sufficient time at combustion temperatures to oxidize to CO_2, the product of ideal combustion. Nitrogen oxides are a result of high combustion temperatures which increase the rate of reaction of free nitrogen and free oxygen to form NO.

It is a further characteristic of jet aircraft engines that combustion efficiency increases with temperature and temperature increases with engine speed. Therefore, at low engine speeds, such as idle conditions, the emissions of CO and HC are at a maximum and NO_x is at a minimum. Conversely, at high engine speeds, such as during takeoff, the combustion efficiency is very near 100 percent and temperatures are at a maximum and therefore NO_x emissions are at a maximum. During takeoff HC and CO emissions are quite low.

5.2.2 Impact of Fuel Conservation Program on Emission Characteristics

The propulsion improvement programs for improving fuel consumption have three areas of concentration: engine component improvement, development of a fuel conservative engine, and development of turboprops as an attractive alternative to jet turbine aircraft. With the exception of the turboprop program, all propulsion improvements for increased fuel economy would involve improving combustion efficiency. This is most important at low power settings such as idle conditions where combustion is least efficient. Improving combustion efficiency would be consistent with and complimentary to efforts for decreasing the emissions of CO and HC at idle conditions (see Refs. (1) – (5)).

The relation between fuel economy and the formation of nitrogen oxides is not as clear cut. As the engine operating temperature increases, the combustion efficiency improves, but there is also an increase in the rate of formation of nitrogen oxides. It could be construed from this that an improvement in fuel economy (combustion efficiency) will cause a corresponding increase in nitrogen oxides emissions; however, recent research

programs have indicated that nitrogen oxide emissions can be reduced without compromising combustion efficiency. The two methods of doing this are water injection into the primary zone and modification of the combustor design. Neither method has a direct impact on combustion efficiency although water injection may increase fuel consumption during takeoff because of the weight penalty of carrying the water.

NASA programs have shown that combustor modification can significantly reduce NO_x emissions without compromising combustion efficiency. Two such designs are the "swirl-can" combustor design and the double annual combustion design.

In summary, it can be concluded from available data that the fuel conservation program will help to reduce the emissions of carbon monoxide and hydrocarbon emissions from jet turbine engines. Also, nitrogen oxide emission increases due to improved combustion efficiency at low power settings can be offset by combustor design or water injection into the primary zone.

5.3 Noise Pollution

5.3.1 Sources of Noise in Aircraft

The two primary sources of noise from aircraft are engine noise and airframe (aerodynamic) noise. Of these, engine noise is the most significant. There are several sources of noise in jet turbine engines. First, most jet turbine engine noise is generated in the fan, while secondary noise sources are core noise and jet noise.

5.3.2 Impact of Improving SFC on Noise Characteristics

5.3.2.1 Jet Turbine Noise

NASA efforts to reduce jet engine noise have been focused at three programs: Refan of current aircraft, Quiet Nacelle Program and Quiet Engine Program. Both the Refan Program and Quiet Engine Program take advantage of higher bypass ratio fan technology which allows for a significant reduction in fan noise and a reduction in specific fuel consumption.

Table 5.1 shows a comparison of estimated noise reduction and specific fuel consumption reduction for JT3D and JT8D aircraft engines retrofitted to take advantage of higher bypass ratio fan technology. More recent data taken from actual flight test measurements indicate that these estimates were in fact realized. Retrofitting 727 aircraft with new quiet fans resulted in 6 to 7 dB noise reductions and 1 to 3% increase in block fuel consumption.* It has been assumed here that changes in block fuel consumption due to engine improvements are directly proportional to improvements in specific fuel consumption. On DC-9 aircraft refan programs resulted in 5 to 11 dB noise reductions and .5-1.0% reduction in block fuel consumption. It is important to note that the data regarding improvements on fuel consumption are estimates only and the refan program is expected to have little if any impact on fuel consumption.

Quiet engine technology employing high bypass ratio technology has resulted in considerable noise reductions over conventional engines. The employment of high bypass ratio fan technology will also result in decreased SFC (Reference 4).

Other engine component improvements are likely to reduce SFC and improve noise characteristics of new generation aircraft. For example, data reported by Pratt and Whitney (Reference 5) indicate that 2 to 5 dB noise reductions can be achieved with a 0-2% reduction in SFC with new mixer technology.

5.3.2.2 Impact of Aerodynamic Improvements for Reduced Fuel Consumption on Aircraft Noise

The two areas of aerodynamic changes that may affect airframe noise are wing design and use of high lift devices. Because these areas of improvement represent the development of new technology, little data can be presented that indicate trends in fuel consumption and noise generation.

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* "Block fuel consumption" is the actual amount of fuel used from one gate at airport to next gate at destination airport.

TABLE 5.1 ESTIMATED NOISE LEVELS AND FUEL CONSUMPTION IMPROVEMENT FOR REFANNED JT3D AND JT8D AIRCRAFT

Engine Type	Aircraft Type & Series	Noise Reduction Due To Refan of Aircraft (PNdB)			Reduction in Specific Fuel Consumption Percent
		Sideline	Takeoff (no cutback)	Approach	
JT3D	DC-8-61	9	--	19	3.1
	DC-8-54F	7	--	18	1.6
	DC-8-51	7	8	18	1.6
	DC-8-62	8	11	19	.2
	DC-8-63	9	12	18	.2
	707-320	13	15	21	3.9
JT8D	DC-9-32	10	11	11	-7.7
	727-200	10	--	13	3.4 to -2.4
AVERAGE		9.4	11.4	16.3	.79 to .06

SOURCE: Noise Source Abatement Technology and Cost Analysis Including Retrofitting, EPA, Aircraft/Airport Noise Study Report, July 1973.

Fuel conservation aerodynamic designs such as high lift devices including externally blown flap aircraft are expected to reduce the impact of noise because of their steep ascent and descent flight paths. This, however, has not been flight tested and represents estimates of design personnel (Reference 7).

In summary, the impact of the fuel conservation program will not interfere and will in most cases be consistent with the noise control programs under development.

5.4 Summary of Air and Noise Impacts

Based on the most current data and estimates available, the program will result in lower aircraft air pollution emission levels and lower noise levels. This conclusion is examined for each program element in Table 5.2. Current programs in reducing air pollution levels and aircraft noise levels have also resulted in lower specific fuel consumption. Efforts to further lower aircraft fuel consumption will result in cleaner, quieter engines and better performance aircraft which implies reduced aircraft emissions and noise levels.

TABLE 5.2 Summary of Impact of Fuel Conservation on Air Pollution and Noise

NASA Fuel Conservation Program Element		Impact on Air Pollution Emissions	Impact on Noise Generation Characteristics
PROPULSION IMPROVEMENTS	Improve Engine Components	Application of advanced fan technology will reduce HC and CO emissions 30 to 60 percent at idle conditions.	Application of advanced fan technology and noise suppression material will significantly lower noise levels.
PROPULSION IMPROVEMENTS	Develop Fuel Conservative Engine	Will reduce levels of all pollutants.	Noise levels will probably be 10 to 20 dB lower than current engines (7 to 10 dB lower than FAR36).
PROPULSION IMPROVEMENTS	Develop Viable Turboprop Aircraft	Will result in significantly lower NO_x Emission Index levels.	Turboprop aircraft are significantly quieter than jet turbine aircraft.
Develop Fuel Conservative Transport		Will reduce levels of all pollutants.	Negligible impact.
Develop Laminar Flow Control Aircraft		(See Note)	No impact.
Develop Composite Primary Aircraft Structures		(See Note)	(See Note)

NOTE: Air pollution levels and noise levels will be reduced due to reduced weight of aircraft and corresponding lower thrust requirements.

6.0 SUMMARY AND CONCLUSIONS

Observations that can be made regarding the NASA Aircraft Fuel Conservation Technology Program are as follows:

- The complete program, on-going plus proposed technology program, which will require an expenditure of $670 million over the time period FY 76-FY 85, has a present worth (in FY 76 dollars) of $425 million at 10% cost of capital. This is equivalent to an annual expenditure of $69 million.
- Implementation of the results of the NASA program will lead to a daily savings of 677,500 barrels of oil by the year 2005, which amounts to a 12% savings relative to no program implementation. In addition, over the time period 1975-2005 the cumulative savings would be 2.08 billion barrels of oil.
- The projected savings to be derived as the result of the NASA program are strongly dependent on the assumed fuel savings to be derived from each of the six technology programs and how quickly the airlines acquire the new and derivative aircraft incorporating the results of this program.
- For every research dollar invested in the NASA program there is a savings of $7.50-$26 in fuel purchase costs.
- By the year 2000, the NASA program would contribute 10% to the National energy savings goal in the area of transportation efficiency.
- The NASA program is designed to yield long-term benefits in the sense that the long-run payoff (i.e., through 2005) to be achieved in terms of savings in barrels per day per FY 76 research dollar spent is on the order of .002, whereas FEA programs in the Buildings, Industrial, Transportation

and Utilities sectors are short-term oriented and are expected to yield payoffs in the range of .18– .65 BPD per FY 76 research dollar spent by 1985.

- Industry funds for aeronautical R&D have decreased by 33% since 1968, thus indicating that industry will contribute less in the future than it has in the past to aeronautical technical advances; hence, in order to achieve technological improvements in aircraft fuel efficiency, Federal program support becomes increasingly more necessary.
- In order to obtain the expected fuel conservation results of the NASA program via private funding would require that private industry double their present level of expenditures for independent research and development.
- In the context of the Project Independence scenarios, implementation of the NASA program would imply a 12-18% transportation energy consumption range in the aviation subsector relative to a present usage of 13%, whereas no program implementation would imply a 12-24% transportation energy consumption range over the period 1985-2005.
- Environmental impacts are expected to include a reduction of carbon monoxide and hydrocarbon emissions from jet turbine engines, and conformance with noise control programs under development.

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8. Aircraft Fuel Conservation Technology Task Force Report, Office of Aeronautics and Space Technology, NASA, 10 September 1975.

APPENDIX A - U.S. DOMESTIC AIR TRAVEL FUEL CONSUMPTION MODEL

Based on domestic aircraft fleet data for a given base year, a postulated schedule for the introduction of new and derivative aircraft from the base year to a specified future reference year, estimated fuel savings of each new or derivative aircraft that is postulated, and a passenger demand forecast, Ultrasystems has developed a computerized model whose primary output is the fuel consumption of the U.S. domestic aircraft fleet for each year from the base year to the future reference year. Some additional outputs available from the model include the fuel consumption rate of each aircraft type in the fleet, the revenue passenger miles (RPM) flown by each aircraft type in each year beginning with the base year, and the total fuel consumed by the fleet from the base year to the future reference year. If the cost of fuel and the cost of capital for each year is input, Ultrasystems model also yields the present worth (in base-year dollars) of the total fuel consumed.

In the subsequent paragraphs of this appendix a detailed description of Ultrasystems' fuel consumption model is presented. To facilitate the description of this model the following notational convention will be adopted. The base year aircraft fleet inventory is partitioned into classes according to type and usage. For example, a typical class might consist of four-engine narrow-body aircraft used on medium stage length routes. These classes will be denoted Class I Mod 1, I = 1,2,... . A postulated aircraft that is to be introduced into the fleet will be designated Class I Mod J if it replaces a Class I aircraft and is the $(J + 1)^{st}$ new or derivative aircraft in that class.

We begin the description of the fuel consumption model by listing the required inputs using the notational convention described:

<u>Input Data</u>

AC(I,1) = Number of aircraft Class I Mod 1 in the inventory in the base year

FBH(I,1) = Fuel consumption per block hour for aircraft Class I Mod 1 (gals)

BHAH(I,1) = Block hour per airborne hour for aircraft Class I Mod 1

SMAH(I,1) = Available seat miles per airborne hour for aircraft Class I Mod 1

ANS(I,1) = Average number of seats on aircraft Class I Mod 1

BKSP(I,1) = Block speed of aircraft Class I Mod 1 (mph)

TAH(I,1) = Total airborne hours per aircraft per year for aircraft Class I Mod 1

NCLAS = Number of aircraft classes

LT(I,J) = Lifetime of aircraft Class I Mod J (yrs)

PFSV(I,J) = Percent fuel savings of aircraft Class I Mod J over aircraft Class I Mod 1

INDT(I,J) = Year aircraft Class I Mod J is ready for introduction into the fleet

MCLAS(I) = Number of modifications (new or derivative aircraft) of aircraft Class I

PGROW(L) = Percent growth in revenue passenger miles for year L over year L-1

ELFAC = Estimated load factor (percent)

JZ(I) = Year aircraft Class I Mod 1 was introduced into the fleet

KZ(I) = Purchase period (prior to base year) of aircraft Class I Mod 1 (yrs)

PRICE(L) = Price per barrel of fuel in year L

DRATE = Discount rate

NYEAR = Number of years between base year and future reference year

We now proceed with a description of the computational methodology employed in Ultrasystems model. The computer program consists of eight subroutines each of which is detailed below.

(1) Fuel Consumption Rate Subroutine

This subroutine calculates the fuel consumption rate in barrels per thousand revenue passenger miles for each aircraft. If the aircraft is in the fleet in the base year (Class I Mod 1) then the fuel consumption rate (FCRT) is obtained via

$$FCRT(I,1) = (355.4)(PFASM(I,1))/ELFAC \quad (I=1,2,\ldots,NCLAS)$$

where

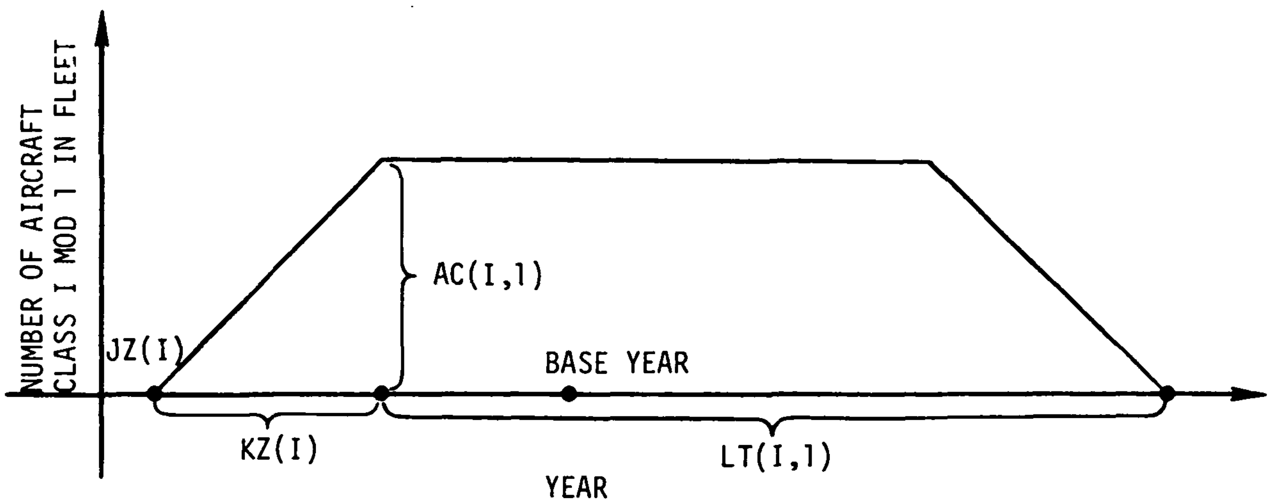
$$PFASM(I,1) = \text{Pounds of fuel per available seat mile for aircraft Class I Mod 1}$$
$$= (6.7)(FBH(I,1)\cdot BHAH(I,1)/SMAH(I,1)$$

For the new or derivative aircraft introduced into the fleet (Class I Mod J, I=1,2,...,NCLAS; J=2,3,...,MCLAS(I)) the fuel consumption rate is given by

$$FCRT(I,J) = FCRT(I,1)(1 - PFSV(I,J)/100.0) .$$

(2) Base Year Aircraft Retirement Schedule Subroutine

For each aircraft in the inventory in the base year this subroutine computes the number retired in subsequent years. Here a linear buy and linear retirement are assumed; that is, the number of aircraft of each Class I Mod 1 in the fleet can be represented as illustrated in the diagram below



Consequently, letting ACRT(I,1,L) denote the number of Class I Mod 1 retired in year L, the model yields for I=1,2,...,NCLAS)

$$ACRT(I,1,L) = \begin{cases} AC(I,1)/KZ(I), & JZ(I) + LT(I) \leq L \leq JZ(I) + LT(I) + KZ(I) \\ 0, & \text{Otherwise} \end{cases}$$

(Note: In the Ultrasystems' computer model the base year is designated year 1 for computational convenience).

(3) RPM By Aircraft Class and Modification for Base Year Subroutine

This subroutine is used to compute for each aircraft its contribution to the total revenue passenger miles (RPM) flown in the base year. Letting RPM(I,J,1) denote the RPM's flown by aircraft Class I Mod J in the base year the model yields

$$RPM(I,J) = \begin{cases} AC(I,J) \cdot RPMAC(I,J), & J=1 \\ 0, & J \neq 1 \end{cases}$$

where

$RPMAC(I,1)$ = Average revenue passenger miles flown each year for each aircraft Class I Mod 1

$= (ELFAC \cdot ANS(I,1) \cdot BKSP(I,1) \cdot BHAC(I,1))/100.0$

$BHAC(I,1)$ = Block hours per aircraft Class I Mod 1

$= BHAH(I,1) \cdot TAH(I,1)$

(4) JMAX Subroutine

This subroutine computes for each aircraft class (I=1,2,...,NCLAS) and each year $L \geq 1$ the latest new or derivative aircraft available in that year. This quantity denoted by JMAX(I,L) is used in the subsequent subroutines.

(5) RPM By Aircraft Class and Modification After Base Year Subroutine

This routine is an iterative scheme for computing the RPM flown by aircraft Class I Mod J in year $L > 1$, RPM(I,J,L). Two assumptions are inherent in this computation:

1) Any replacement aircraft required (due to retirement or RPM growth) for Class I aircraft in year L are replaced by latest replacement aircraft available, i.e., by aircraft Class I Mod JMAX(I,L).
2) The rate of growth of the RPM per aircraft class in any given year is the same as the overall rate of growth of RPM for that year.

(6) Total Fuel Consumption by Year Subroutine

This subroutine computes the total fuel consumption in barrels for each year L and is denoted by TFC(L). This subroutine utilizes FCRT(I,J) and RPM(I,J,L) and is calculated via

$$\mathrm{TFC(L)} = \sum_{I=1}^{\mathrm{NCLAS}} \sum_{J=1}^{\mathrm{MCLAS(I)+1}} (\mathrm{RPM(I,J,L)} \cdot \mathrm{FCRT(I,J)})/1000.0$$

(7) Total Fuel Consumption Subroutine

Here the fuel consumption by year computed in the previous subroutine is cumulated to give the total fuel consumption TOTFC. Thus

$$\mathrm{TOTFC} = \sum_{L=1}^{\mathrm{NYEAR}} \mathrm{TFC(L)}$$

(8) Present Worth Subroutine

Here the present worth (in base year dollars) of the total fuel consumed is computed. Letting PREW denote this quantity, the program yields

$$\mathrm{PREW} = \sum_{L=1}^{\mathrm{NYEAR}} \frac{\mathrm{TFC(L)\ PRICE(L)}}{[1 + \mathrm{DRATE}]^{L}} \ .$$

APPENDIX B - COMPARISON OF FUEL CONSUMPTION ANALYSES

In Section 2.1 fuel consumption forecasts were developed for two basic scenarios, namely: (1) Baseline Without NASA Program and (2) Baseline With NASA Program. These scenarios were developed according to assumptions and considerations presented in Section 2.1. On the other hand, slightly different scenarios can be constructed using the information developed by the Task Force and presented in Reference 8, and which can be referred to as the Task Force Baseline and the Task Force Total Program. The assumed characteristics of these scenarios are as follows:

<u>CASE: Task Force Baseline</u>

(a) In 1978, a derivative medium-range aircraft will be introduced into service to replace the current fleet of 3-engine narrow body aircraft. This new aircraft could be the refanned B-727-300, or, somewhat later, an aircraft using the high-bypass-ratio GE/Snecma CFM56 or the P&W JT10D engines, or possibly a derivative twin-engine wide-body. This new aircraft is estimated to have a 15% improvement in SFC over the current B-727 fleet, to provide an average fuel use of 1.251 bbl per thousand RPM.

(b) In 1983, a derivative long-range aircraft will be introduced into service. This aircraft will most likely be a stretched version of the current B-747, DC-10 or L-1011. The improvement in fuel consumption as compared to the existing wide-body aircraft is estimated at 10%, to give an average fuel use of .793 bbl per thousand RPM.

(c) In 1988, at the projected growth rate, the short-range market will require the introduction of a new aircraft to satisfy the demand. This aircraft will probably not be very different from the existing DC-9's because of the special constraints of the short-haul market, particularly in terms of average stage length, traffic density and number of competitors.

This aircraft is assumed to be 20% more efficient than the current two-engine narrow-body aircraft and to provide an average fuel consumption of 1.182 bbl per thousand RPM.

Table B.1 provides a summary of this forecast.

CASE: Task Force Total Program

(a) Continued Production Aircraft

The results of the Engine Component Improvement program will be available in 1980 and could be used on new production of existing engine types shortly thereafter. An improvement of 5% in SFC for all twin-engine narrow-body aircraft introduced into service after 1982 is estimated to result from this technology element.

(b) Derivative Aircraft

The derivative three-engine narrow-body aircraft produced after 1978 would also benefit from the Engine Component Improvement program and would be 15% more efficient than aircraft that would have been produced without this technology. The net result would be that the derivative medium-range aircraft introduced into service after 1982 would have a 20% improvement in fuel consumption as compared with current three-engine narrow-body aircraft.

It is expected that the derivative three- or four-engine wide-body aircraft introduced in 1983 would benefit from both the Engine Component Improvement program and from the Fuel Conservative Transport program. This aircraft would have reduced static stability for lower trim drag and an improved wing in addition to a more efficient engine. These two technologies would result in a 10% improvement over the aircraft that would have otherwise been produced, or a 20% improvement in fuel use as compared to the current wide-body aircraft.

TABLE B.1 Task Force Baseline Forecast of Aircraft Fleet Mix

MOD 1	MOD 2	MOD 3	MOD 4	MOD 5	MOD 6
CLASS 1 TF 4 ENG WB (B-747)	D3/4EWB INT = 83 PFSV = 10				
CLASS 2 TF 3 ENG WB (DC-10, L-1011)	D3/4EWB INT = 83 PFSV = 10				
CLASS 3 TF 4 ENG NB (LONG STAGE) (B-707, DC-8, C-990, B-720)	CURRENT TF 3 ENG WB INT = 75	D3/4EWB INT = 83 PFSV = 10			
CLASS 4 TF 4 ENG NB (MEDIUM STAGE) (B-707, DC-8, C-990, B-720)	CURRENT TF 3 ENG NB INT = 75	D3ENB INT = 78 PFSV = 15			
CLASS 5 TJ 4 ENG NB (B-707, DC-8, C-880)	CURRENT TF 3 ENG NB INT = 75	D3ENB INT = 78 PFSV = 15			
CLASS 6 TF 3 ENG NB (B-727)	D3ENB INT = 78 PFSV = 15				
CLASS 7 TF 2 ENG NB (B-737, DC-9, BAC-111)	D2ENB INT = 88 PFSV = 20				

LEGEND

INT = Date of introduction
D = Derivative
TF = Turbofan
E = Engine
WB = Wide body
NB = Narrow body
3/4 = 3 or 4
PFSV = Percent fuel savings
N = New aircraft
TP = Turboprop

(c) New Production Aircraft

The new medium-range aircraft introduced in 1985 would benefit from the use of composites in the vertical tail and in secondary structures such as the floorboards, elevons, slats, etc. The new aircraft would be 15% more efficient than the 1982 derivative three-engine narrow-body aircraft, and provide a 35% improvement in fuel use as compared with current aircraft.

By 1988, when a new narrow-body short-range aircraft is introduced, it should be possible to make extensive use of composites for the primary structures and to incorporate substantial aerodynamic improvements in the aircraft design. Assuming that a reliable turboprop engine has been demonstrated, this new short-haul aircraft would be a likely candidate for that propulsion system. The combination of all these technology elements is estimated to result in a new aircraft that is 45% more efficient than the 1982 continued-production aircraft, or 50% better than the twin-engine narrow-body aircraft in the current fleet.

Partly because of the expected benefits of this concentrated technology development program, two additional aircraft are expected to be introduced into service before the end of the century. The first of these, a new long-range wide-body aircraft, could be introduced in 1990 and is expected to provide a 30% improvement in fuel use as compared to the derivative wide-body aircraft, or 50% as compared to the existing B-747's, DC-10's, and L-1011's. This new aircraft would have an improved engine, composite primary structures, active controls, optimized aerodynamic design, and could also have a laminar flow control system, provided the technology demonstration is successful.

The second aircraft to be introduced in the 1990's would be a new medium-range transport that could come into service in 1995. This aircraft would incorporate many of the improvements that were applied to the 1990 wide-body aircraft. A turboprop propulsion system might also prove to be very attractive for an aircraft of this size and design range. This new aircraft is estimated to be 25% more efficient than the new medium-range aircraft introduced in 1985, ten years earlier, and would provide

an overall improvement in fuel use of 50% as compared to the existing B-727's.

Table B.2 provides a summary of this forecast.

Table B.3 provides a comparison of the Task Force scenarios with the Ultrasystems scenarios postulated in Section 2.1. As can be seen, the Ultrasystems scenarios are more conservative in the estimates of savings obtained; however, they show a larger fuel consumption because of the higher annual growth rate in RPM.

TABLE B.2 Task Force Total Program Forecast of Aircraft Fleet Mix

MOD 1	MOD 2	MOD 3	MOD 4	MOD 5	MOD 6
CLASS 1 TF 4 ENG WB (B-747)	D3/4EWB INT = 83 PFSV = 20	N3/4EWB INT = 90 PFSV = 50			
CLASS 2 TF 3 ENG WB (DC-10, L-1011)	D3/4EWB INT = 83 PFSV = 20	N3/4EWB INT = 90 PFSV = 50			
CLASS 3 TF 4 ENG NB (LONG-STAGE) (B-707, DC-8, C-990, B-720)	CURRENT TF 3 ENG WB INT = 75	D3/4EWB INT = 83 PFSV =20	N3/4EWB INT = 90 PFSV = 50		
CLASS 4 TF 4 ENG NB (MEDIUM STAGE) (B-707, DC-8, C-990, B-720)	CURRENT TF 3 ENG NB INT = 75	D3ENB INT =78 PFSV = 15	D3ENB INT = 82 PFSV = 20	N3ENB INT = 85 PFSV = 35	N3ENB (TP) INT = 95 PFSV = 50
CLASS 5 TJ 4 ENG NB (B-707, DC-8, C-880)	CURRENT TF 3 ENG NB INT = 75	D3ENB INT =78 PFSV = 15	D3ENB INT = 82 PFSV = 20	N3ENB INT = 85 PFSV = 35	N3ENB (TP) INT = 95 PFSV = 50
CLASS 6 TF 3 ENG NB (B-727)	D3ENB INT =78 PFSV = 15	D3ENB INT = 82 PFSV = 20	N3ENB INT = 85 PFSV = 35	N3ENB(TP) INT = 95 PFSV = 50	
CLASS 7 TF 2 ENG NB (B-737, DC-9, BAC-111)	D2ENB INT = 82 PFSV = 5	N2ENB(TP) INT = 88 PFSV = 50	LEGEND INT = Date of introduction D = Derivative TF = Turbofan E = Engine WB = Wide body	NB = Narrow body 3/4 = 3 or 4 PFSV = Percent fuel savings N = New aircraft TP = Turboprop	

TABLE B.3 Comparison of Fuel Consumption (in Billion Barrels) With NASA Task Force Forecasts

FLEET MIX SCENARIO	ANNUAL FUEL CONSUMPTION 1985	1990	1995	2000	2005	CUMULATIVE CONSUMPTION 1975-2005
Task Force Baseline[(1)]	.3465	.4046	.4790	.5708	.6904	13.331
Task Force Total Program[(1)]	.3410	.3726	.3948	.3912	.4175	11.041
Savings	.0055 (1.6%)	.0320 (7.9%)	.0842 (17.6%)	.1996 (35.0%)	.2729 (39.5%)	2.290 (17.2%)
Baseline Without NASA Program[(2)]	.4609	.5632	.6909	.8029	.9556	17.948
Baseline With NASA Program[(2)]	.4559	.5439	.6006	.6415	.7083	15.873
Savings	.0050 (1.0%)	.0193 (3.4%)	.0903 (13.1%)	.1614 (20.1%)	.2473 (25.9%)	2.075 (11.6%)

(1) Assumes 4% RPM growth rate per year.
(2) Assumes 7% RPM growth rate per year to 1985 and 5.5% RPM growth rate per year in 1986-2005.

APPENDIX C - COMPUTER INPUTS FOR BASELINE AND NASA PROGRAM FUEL CONSUMPTION CALCULATIONS

TABLE C-1 Current Inventory Input Data

Aircraft Category	Input Data							Data Computed From Current Inventory Data	
	Number of Aircraft	Fuel Consumption Per Block Hour (gal)*	Block Hour Per Airborne Hour*	Available Seat Miles Per Airborne Hour*	Average Number of Seats*	Block Speed (mph)	Total Airborne Hours Per Aircraft Per Year*	Fuel Consumption Rate (bbls/1000 RPM	RPM Per Aircraft Per Year
Class 1 Mod 1 TF 4 ENG WB (B-747)	111	3,349.0	1.095	160,678	317.1	463	3,147.17	.9881	278.29×10^6
Class 2 Mod 1 TF 3 ENG WB (DC-10, L-1011)	175	2,188.0	1.139	108,175	223.7	425	2,787.21	.9974	166.00×10^6
Class 3 Mod 1 TF 4 ENG NB (Long-Stage) (B-707, DC-8, C-990, B-720)	244	1,782.0	1.115	62,639	133.3	421	3,012.71	1.373	103.69×10^6
Class 4 Mod 1 TF 4 ENG NB (Medium-Stage) (B-707, DC-8, C-990, B-720)	244	1,782.0	1.115	62,639	133.3	421	3,012.71	1.373	103.69×10^6
Class 5 Mod 1 TJ 4 ENG NB (B-707, DC-8, C-880)	142	2,016.0	1.138	53,214	116.5	401	2,610.78	1.867	76.34×10^6
Class 6 Mod 1 TF 3 ENG NB (B-727)	753	1,326.0	1.184	46,072	107.5	363	2,609.31	1.475	66.31×10^6
Class 7 Mod 1 TF 2 ENG NB (B-737, DC-9, BAC-111)	535	901.5	1.217	32,027	87.1	304	2,548.91	1.483	45.18×10^6

*SOURCE: Civil Aeronautics Board Aircraft Operating Cost and Performance Report 1972.

TABLE C-2 Introduction Dates, Service Life and Fuel Savings Input Data for Baseline Without NASA Program Forecast of Aircraft Fleet Mix

MOD 1	MOD 2	MOD 3	MOD 4	MOD 5	MOD 6
CLASS 1 TF 4 ENG WB (B-747) 15 YR LIFE	INT = 80 PFSV = 18 15 YR LIFE	INT = 90 PFSV = 35 15 YR LIFE			
CLASS 2 TF 3 ENG WB (DC-10, L-1011) 15 YR LIFE	INT = 80 PFSV = 10 15 YR LIFE	INT = 85 PFSV = 20 15 YR LIFE	INT = 90 PFSV = 35 15 YR LIFE		
CLASS 3 TF 4 ENG NB (Long-Stage) (B-707, DC-8, C-990, B-720) 15 YR LIFE	TF 3 ENG WB INT = 75 15 YR LIFE	INT = 80 PFSV = 10 15 YR LIFE	INT = 85 PFSV = 20 15 YR LIFE	INT = 90 PFSV = 35 15 YR LIFE	
CLASS 4 TF 4 ENG NB (Medium-Stage) (B-707, DC-8, C-990, B-720) 15 YR LIFE	**SAME AS CLASS 6 MOD 1**	INT = 83 PFSV = 20 15 YR LIFE	INT = 95 PFSV = 30 15 YR LIFE		
CLASS 5 TJ 4 ENG NB (B-707, DC-8, C-880) 15 YR LIFE	**SAME AS CLASS 6 MOD 1**	INT = 83 PFSV = 20 15 YR LIFE	INT = 95 PFSV = 30 15 YR LIFE		
CLASS 6 TF 3 ENG NB (B-727) 22 YR LIFE	INT = 83 PFSV = 20 15 YR LIFE	INT = 95 PFSV = 30 15 YR LIFE			
CLASS 7 TF 2 ENG NB (B-737, DC-9, BAC-111) 15 YR LIFE	INT = 82 PFSV = 5 15 YR LIFE	INT = 90 PFSV = 25 15 YR LIFE			

TABLE C-3 Introduction Dates, Service Life and Fuel Savings Input Data for Baseline With NASA Program Forecast of Aircraft Fleet Mix

MOD 1	MOD 2	MOD 3	MOD 4	MOD 5	MOD 6
CLASS 1 TF 4 ENG WB (B-747) 15 YR LIFE	INT = 80 PFSV = 18 15 YR LIFE	INT = 85 PFSV = 30 15 YR LIFE	INT = 92 PFSV = 50 15 YR LIFE		
CLASS 2 TF 3 ENG WB (DC-10, L-1011) 15 YR LIFE	INT = 80 PFSV = 10 15 YR LIFE	INT = 85 PFSV = 28 15 YR LIFE	INT = 92 PFSV = 50 15 YR LIFE		
CLASS 3 TF 4 ENG NB (Long-Stage) (B-707, DC-8, C-990, B-720) 15 YR LIFE	TF 3 ENG WB INT = 75 15 YR LIFE	INT = 80 PFSV = 10 15 YR LIFE	INT = 85 PFSV = 28 15 YR LIFE	INT = 92 PFSV = 50 15 YR LIFE	
CLASS 4 TF 4 ENG NB (Medium-Stage) (B-707, DC-8, C-990, B-720) 15 YR LIFE	SAME AS CLASS 6 MOD 1	INT = 82 PFSV = 25 15 YR LIFE	INT = 90 PFSV = 50 15 YR LIFE		
CLASS 5 TJ 4 ENG NB (B-707, DC-8, C-880) 15 YR LIFE	SAME AS CLASS 6 MOD 1	INT = 82 PFSV = 25 15 YR LIFE	INT = 90 PFSV = 50 15 YR LIFE		
CLASS 6 TF 3 ENG NB (B-727) 22 YR LIFE	INT = 82 PFSV = 25 15 YR LIFE	INT = 90 PFSV = 50 15 YR LIFE			
CLASS 7 TF 2 ENG NB (B-737, DC-9, BAC-111) 15 YR LIFE	INT = 82 PFSV = 10 15 YR LIFE	INT = 90 PFSV = 50 15 YR LIFE			